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ABUNDANCES OF THE NOBLE GASES IN THE ATMOSPHERE AND IN METEORITES

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The rare gases are excellent tracers of geochemical events. Harrison Brown (1949) published Figure 1 in 1949. The idea was to calculate the fraction of the rare gases that was still in the atmosphere. It is assumed that the original amounts present were those now observed in the sun, partly from astronomical observations and partly from interpolations. One of the curves shown in Figure 1 corresponds to the values for the amounts of rare gases in the earth's atmosphere, and the other includes also the amounts of gas that might still be in the mantle. Hence the points on the graph correspond to upper and lower limits for the factors by which terrestrial abundances of the rare gases must be multiplied to obtain the amounts observed in the sun. One sees that ~10,000 times as much xenon was retained compared to neon. This means that a very effective separation of neon and xenon must have taken place. The other gases lie between neon and xenon on a remarkably smooth curve.

Independently and essentially simultaneously from the work by Harrison Brown, I published a very similar graph shown in Figure 2 (Suess, 1949), with the only difference being that it is 180° out of phase with Figure 1. The vertical scale indicates the factor by which the earth is depleted in neon, argon, krypton, and xenon. One wonders what mathematical function would correspond to a curve such as shown in Figures 1 and 2. If one wants to explain the depletion as a result of escape of the rare gases from a gravitational field, then one does indeed get a curve of such a type. One finds that the depletion factor N_{ter}/N_{sol} depends on the atomic mass m according to

$$-\log \frac{N_{ter}}{N_{sol}} = Ae^{-\beta m} + B$$

A difficulty is that the exponent β in this equation comes out to be very small and of the order of 0.05. Such a small exponent corresponds to either a very high temperature or a very low gravitational field. The high temperature is impossible, but the low gravitational field can be realized in several ways. The general conclusion is that the gases must have escaped from the solids before the earth had acquired its present mass. Separation, according to such a function, would of course include the

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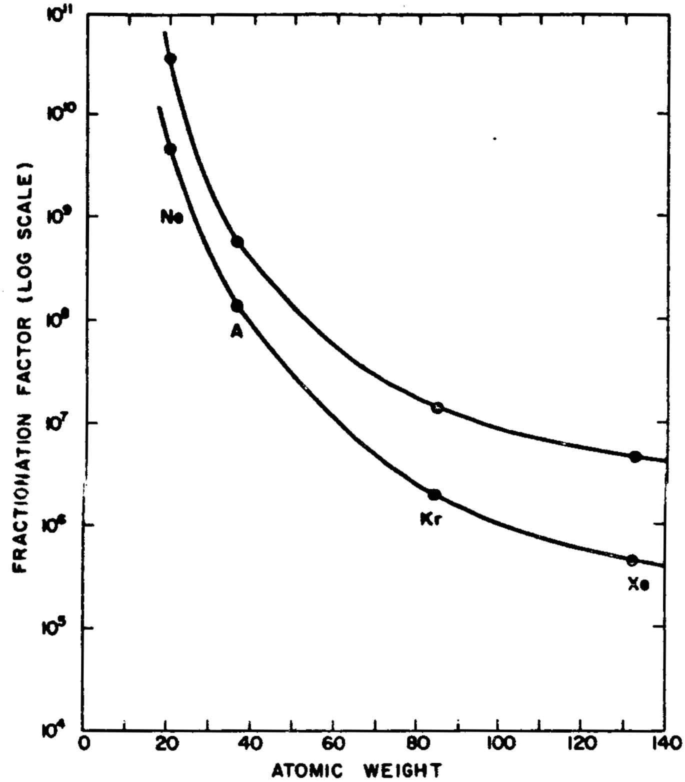

Figure 1. Fractionation factors for noble gases according to Harrison Brown (1949). The upper curve includes the amounts of gases possibly included in the interior of the earth. The lower curve refers to the noble gases contained in the atmosphere alone.

separation of isotopic nuclides, in particular that of Ne^{20} from Ne^{22} and Ar^{36} from Ar^{38}.

The other possibility is that the fractionation curve is the consequence of chemical effects involving, for example, adsorption and solution phenomena of the gases. In this case, however, one would not expect any marked shift in the isotopic composition of the rare gases.

Recent work by Reynolds, Gerling and Levski, Nier, Signer, Stauffer, Eberhardt, Zahringer, and others, on rare gases in meteorites, makes it now possible to compare rare gases on the earth with those contained in

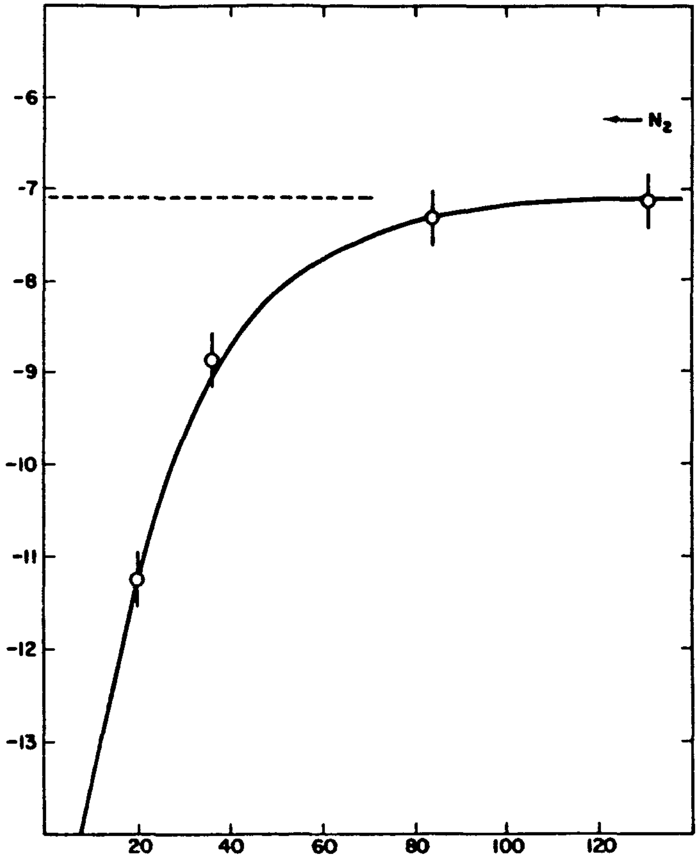

Figure 2. Log of depletion factors of noble gases on the earth relative to their solar abundances plotted against atomic weight according to H. E. Suess (1949).

meteorites and with those in the sun. The main question now is whether the rare gas fractionation is due to the mass difference, or is of a chemical nature. The data from meteorites clearly show a variation in the isotopic composition of neon. The situation is complicated by the fact that in many meteorites the rare gases have been fractionated in a similar way as those in the terrestrial atmosphere. Figure 3 shows this. It shows the abundances of rare gases in meteorites as published by Reynolds (1961). In many meteorites the rare gases seem to be mixtures of two types of different isotopic and elemental composition that were fractionated through a different mechanism.

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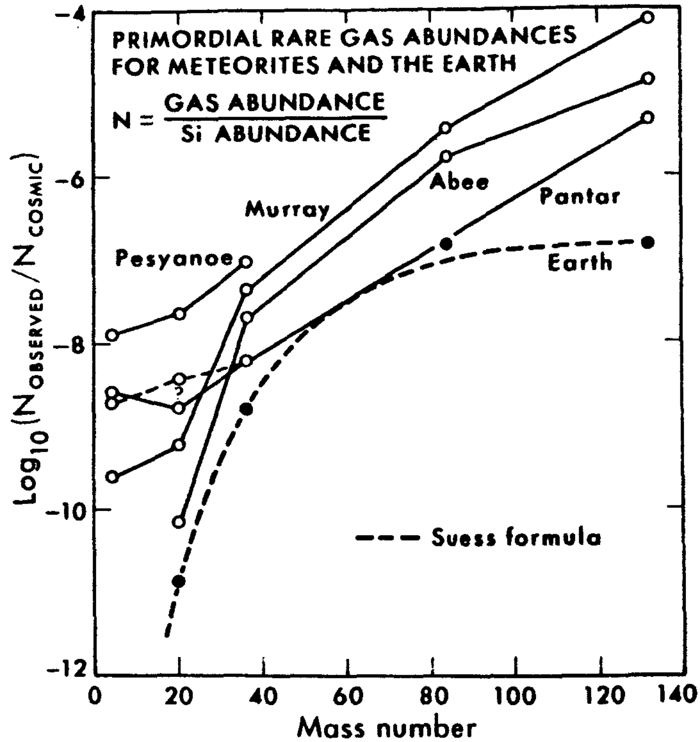

Figure 3. Abundances of rare gases in meteorites according to Reynolds (1961).

The first meteorites that were studied for their rare gas content contained considerably higher concentrations of rare gases per silicon atom than the atmosphere contains in relative comparison with the total silicon in the earth. However, if other meteorites are included which contain much smaller amounts of rare gases, and if one adjusts these values a little bit from modern data, one finds that rare gas abundances on the earth are very close to those of the chondritic meteorites, such as the Bruderheim meteorite. This can also be seen in Figure 4.

Regarding the difference in the isotopic composition of terrestrial and solar neon and argon there is a numerical error in the last table of my paper of 1949, that predicts the isotope separation according to the function shown in Figure 2. The whole argument, however, is of a qualitative nature, and only effects in the right direction and of the right order should be expected. In this respect, my paper has been occasionally misunderstood.

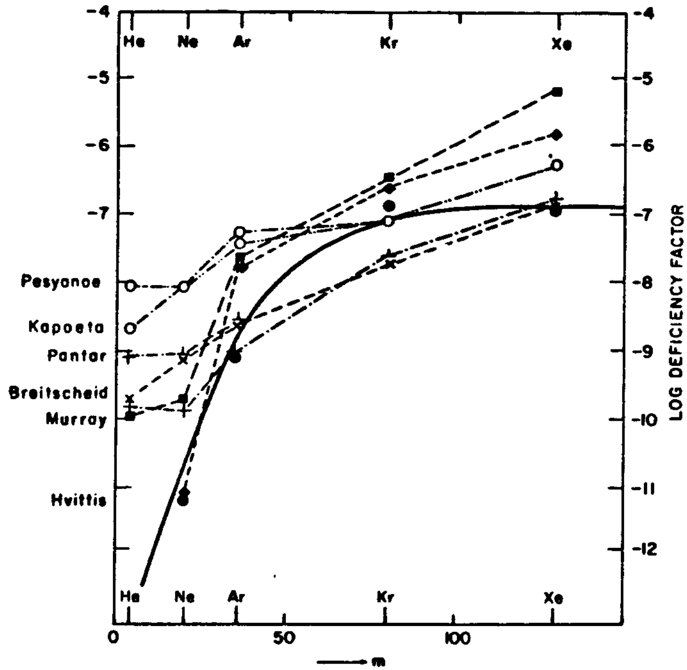

Figure 4. Abundances of rare gases in meteorites after Signer and Suess (in press).

Regarding the question, whether the rare gases now in the terrestrial atmosphere were derived by degassing the mantle, or whether they have been there from the beginning, the most conclusive evidence has been presented by Reynolds, who found excess Xe^{129} in gases from the interior of the earth. If one assumes that the excess Xe^{129} originated from I^{129} some 4.5 aeons ago, then the rare gases in the atmosphere did not come from outgassing of the mantle. The consequences of such a conclusion would be very important, because one would then also have to assume that the oceans did not come from the interior of the earth, but were present at a very early time when the earth was formed.

References

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Reynolds, J. M. (1960) J. Geophys. Res., 65, 3843.

Discussion

Anders: Is there any meaning to the average rare gas content of meteorites?

Suess: Not yet, but I am merely interested in whether there is more rare gas, or less rare gas in meteorites than there is in the atmosphere. It is not out of line to assume that there was no gas when the meteorites formed and that the gases in the earth's atmosphere were derived from degassing of solid material. However, if Reynolds finds Xe^{129} in the deeper layers then I would prefer the opinion that there was a slight atmosphere at the place where the earth formed containing water and small amounts of the original rare gases. These then lead to the formation of the atmosphere. I think it is quite important to think about these things. I do not know the answer, but with this type of work we will find it.

Epstein: It seems to me that the ocean water is independent of the rare gases.

Suess: I do not think you can bring up water and leave the xenon inside.

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